Examining GLM and LMA flash rates in the context of radar observations

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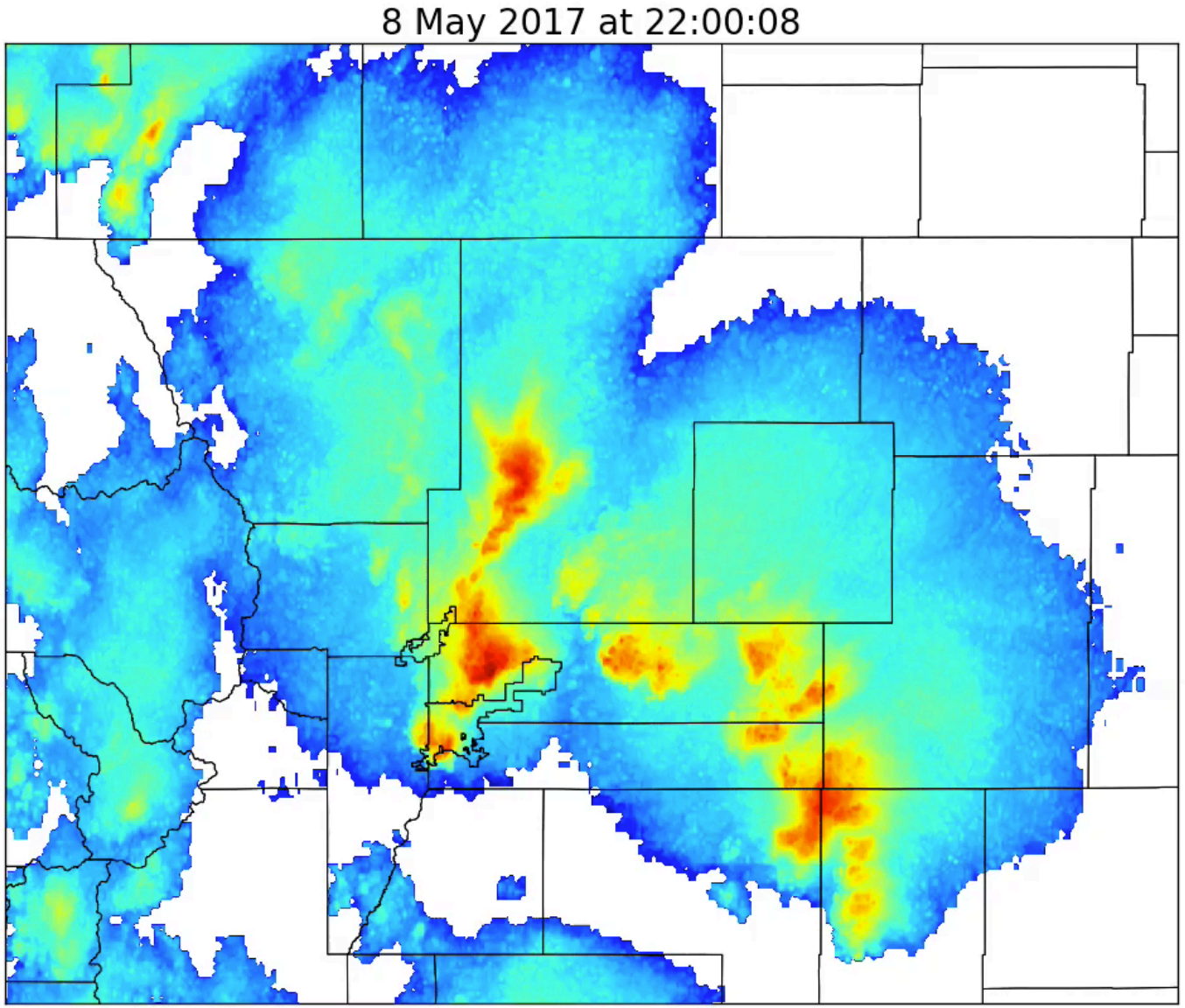
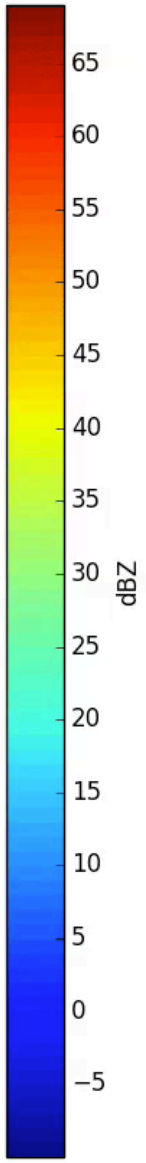
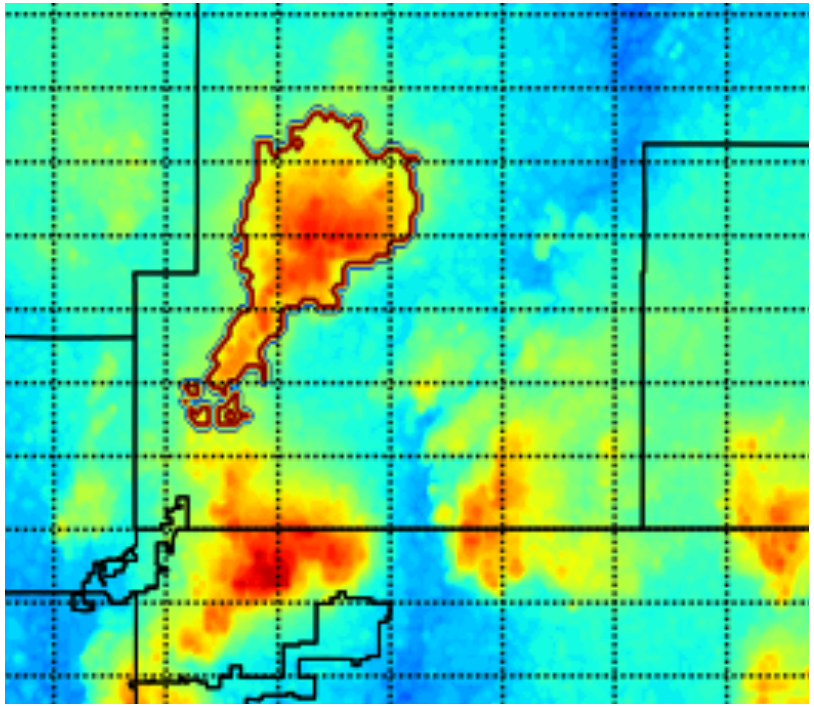
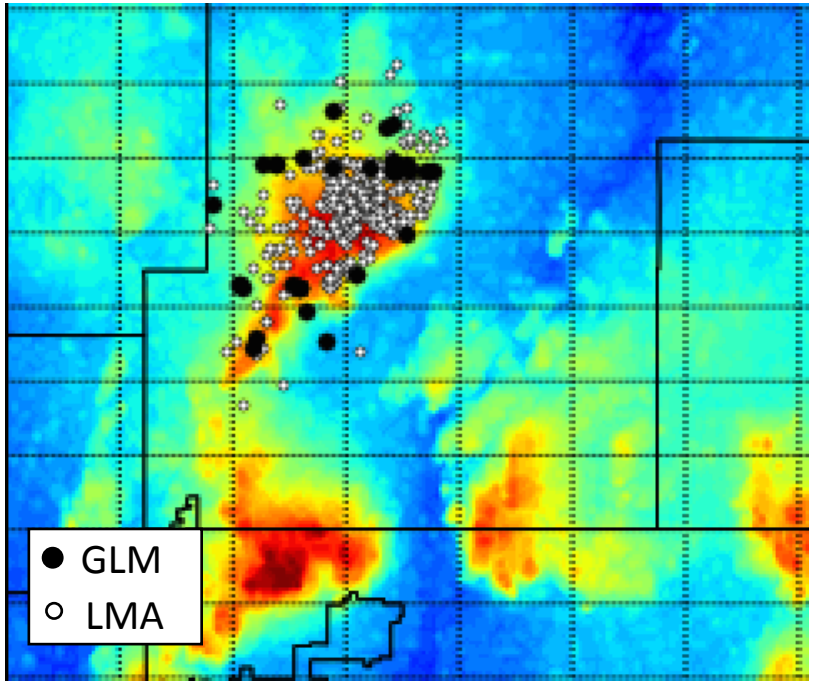




GLM Cal/Val Field Campaign

- May 8, 2017 ”Gold Mine” mission over Colorado
- NASA ER-2 on station from 22:00 to 01:00 UTC
- CSU-CHILL radar operated to assist in campaign efforts
- Multiple hail producing supercells observed
- Both anomalous and normal polarity storms present during the ER-2 mission period

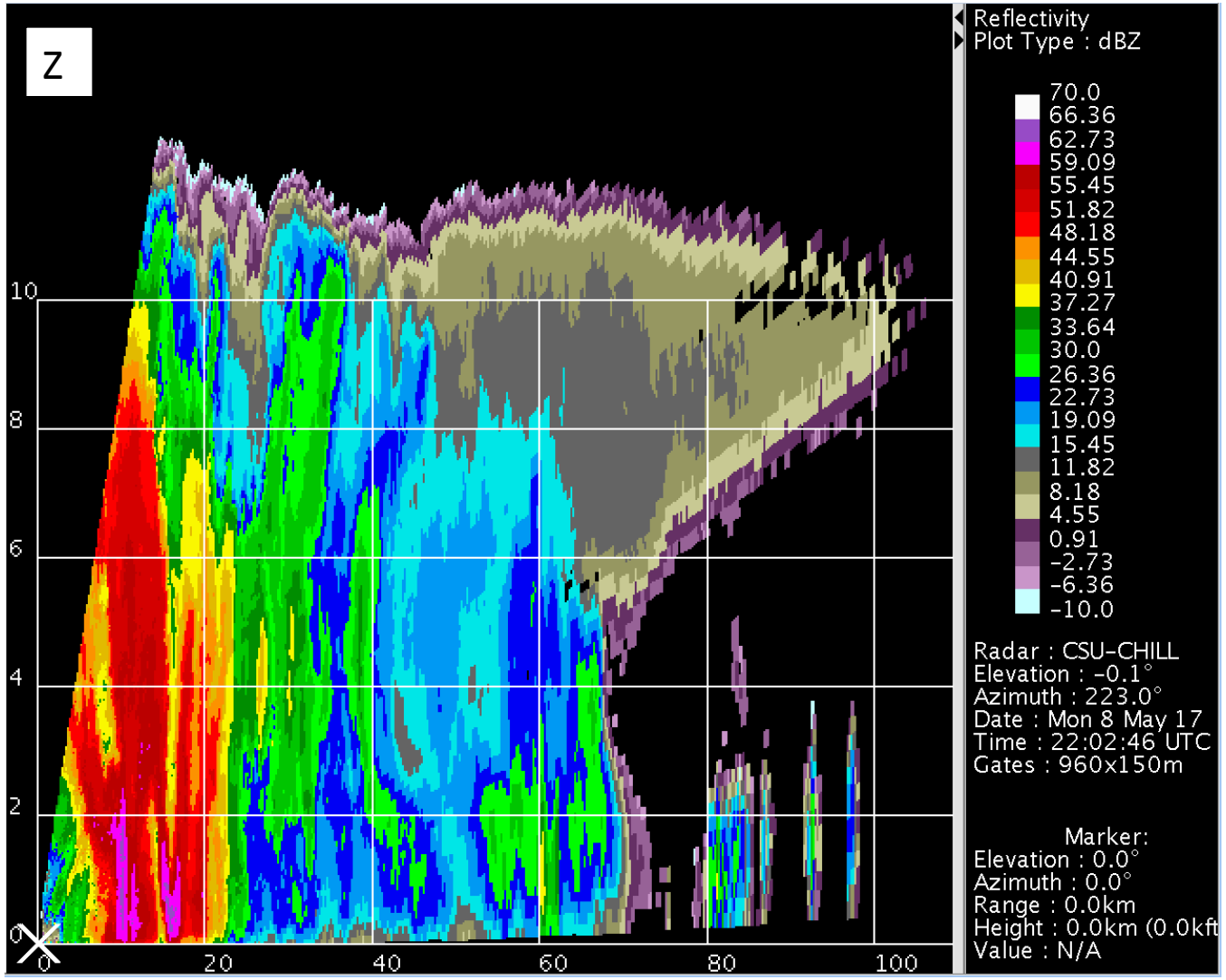


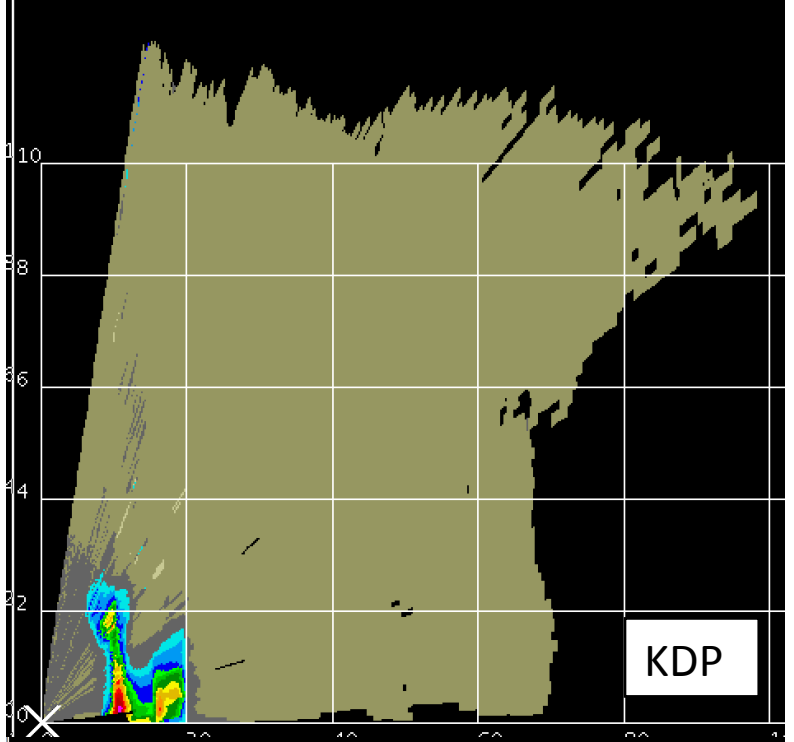


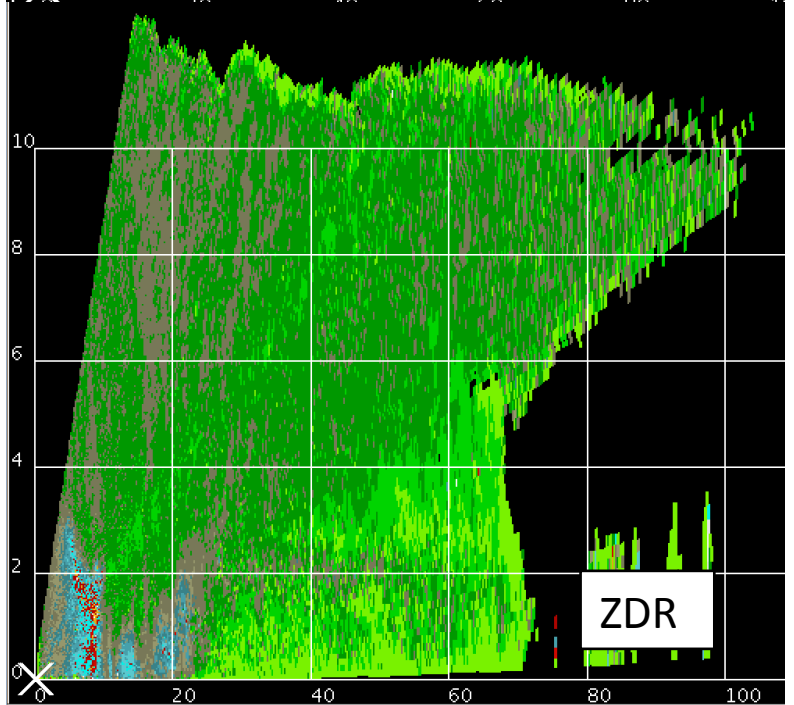
Methodology

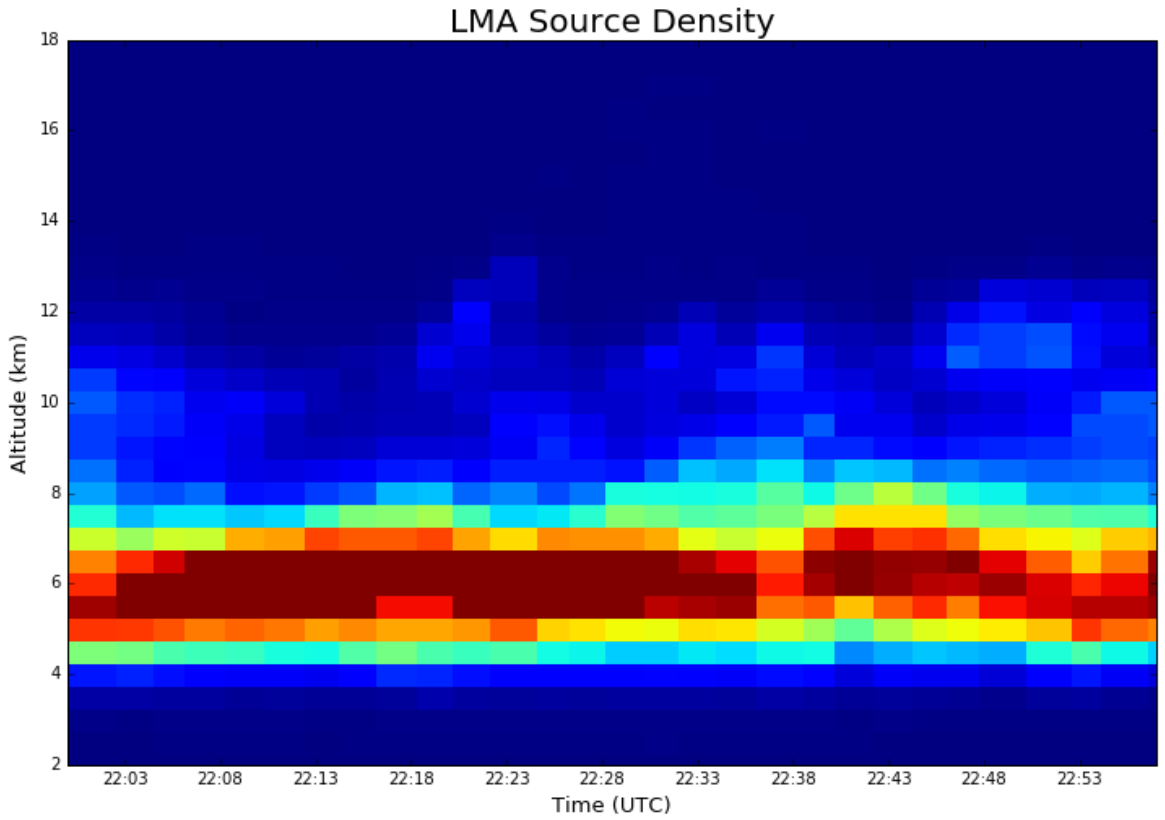
- Utilize the CSU Lightning, Environment, Aerosol, and Radar (CLEAR) framework to identify storm cells outlined by the 35 dbZ contour of composite reflectivity (Lang and Rutledge, 2011)
- Assign GLM (L2) and LMA flashes to each storm cell through a flash attribution algorithm
  - LMA flashes are attributed if they are within 10 km of the cell outline
  - GLM flashes are attributed if they are within 15 km of the cell outline to account for possible flash location errors
- LMA sources are grouped into flashes through a flash clustering algorithm (Fuchs et al. 2015)—conservative estimate implied by the following thresholds
  - Requirements:
    - 10 LMA sources
    - 16.5 km maximum distance between sources (3 km normally used)
    - 330 ms maximum time difference between sources (150 ms normally used)
- Flashes attributed to individual storms are used to calculate minute by minute flash rates. Keep in mind LMA measures VHF radiation from lightning and GLM detects optical emissions. So direct comparison between LMA and GLM is a bit dubious.

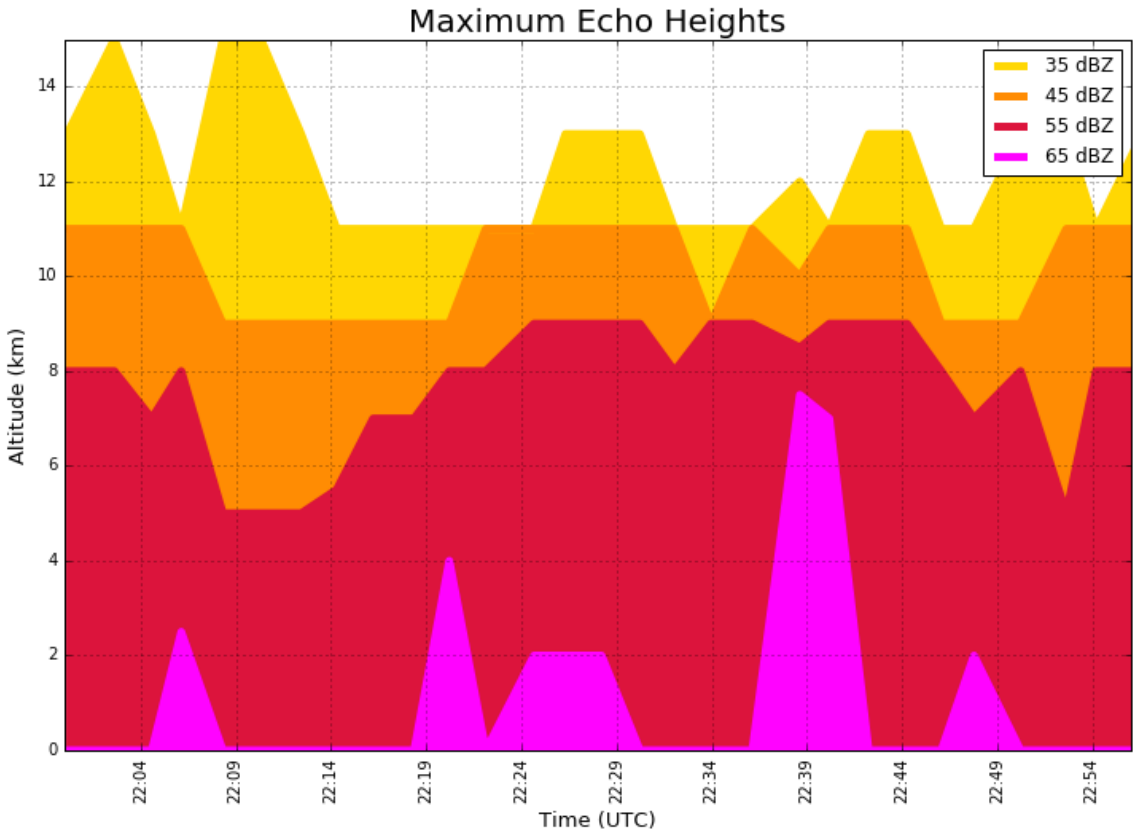
Greeley Anomalous Polarity Storm



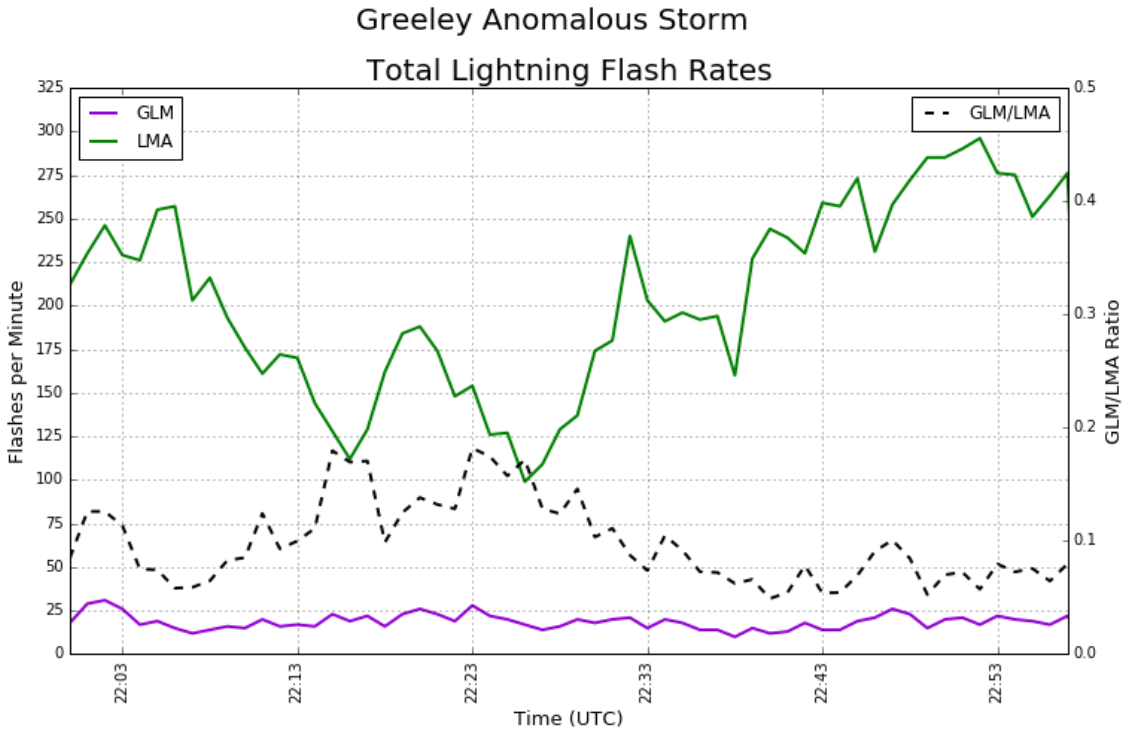


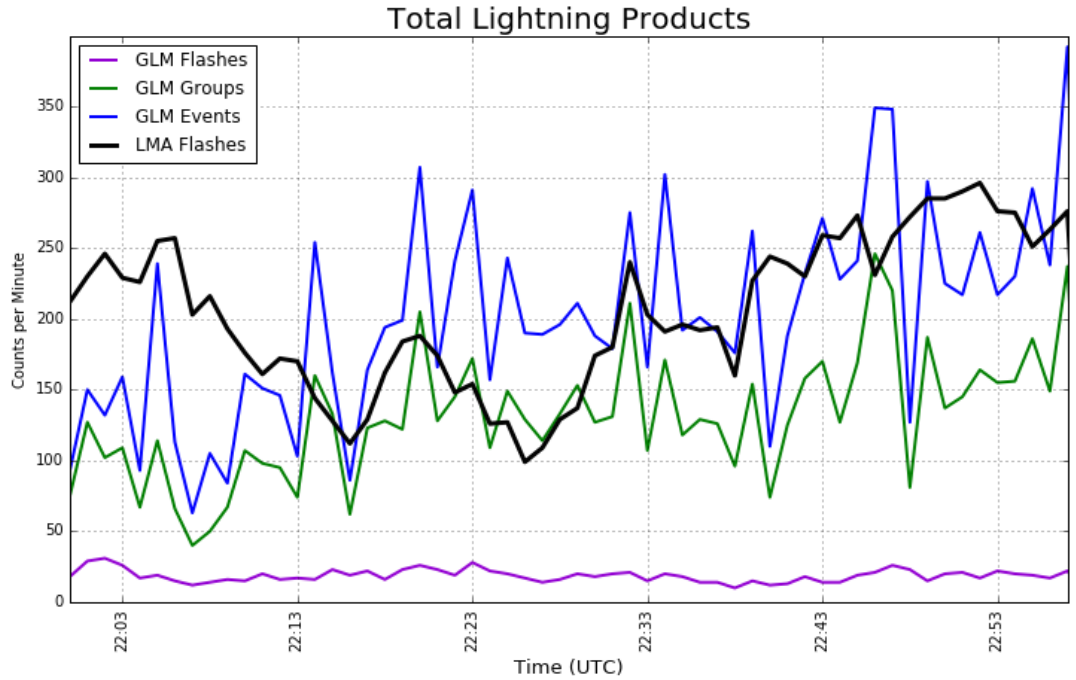






- LMA sources are concentrated near 6 km throughout the duration of the analysis period; we identify this as a “anomalous” storm, with enhanced low level positive charge
- Greeley anomalous storm is very intense, displaying multiple regions of 65 dBZ extending to 8 km agl



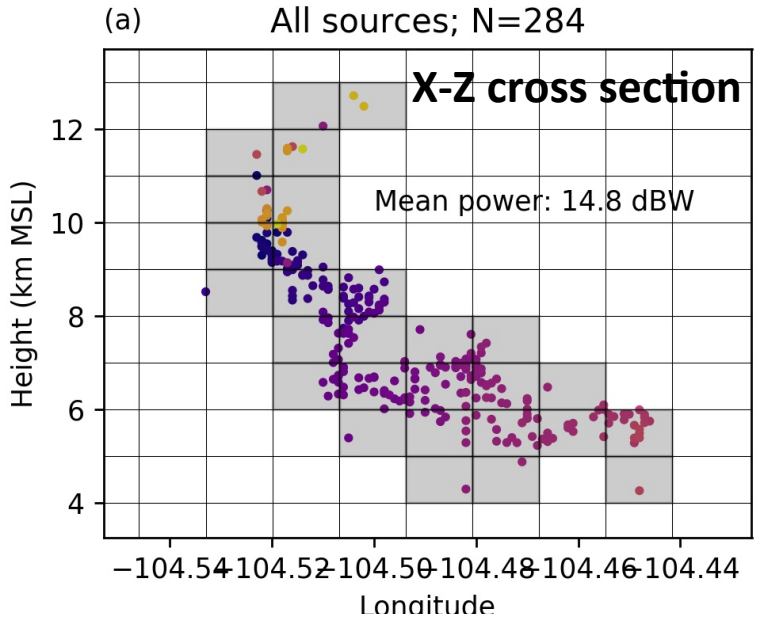


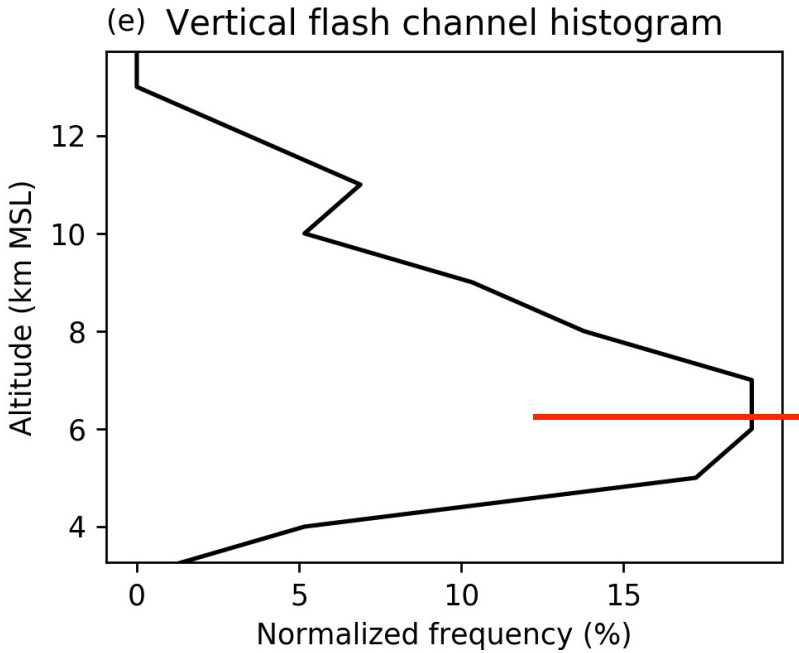
Greeley Anomalous Polarity Storm

- GLM produces fewer flashes with little variance in flash rate compared to LMA, the latter showing a factor of 2 variation in FR
- GLM/LMA ratio (~detection efficiency) averages near 0.1
- Largest DE occurs when the LMA FR is a minimum
- GLM events and groups are roughly the same magnitude as LMA flash rates
- GLM events and groups show a gradual increase in minute by minute counts, but GLM flashes do not

Flash channel height calculation

- Impose a grid over each flash identified by the algorithm
- Any grid box/cube that contains an LMA source is considered to have contained a segment of the flash
- Binary: 1 or 0 in each box
- 3D extension of flash extent density
- Add them up for all flashes in a volume/ cell
- Define median flash height as the mode of the vertical distribution
- Interested in seeing if DE is coupled to flash channel height?
- We will also link DE to flash channel area following the method of E. Bruning

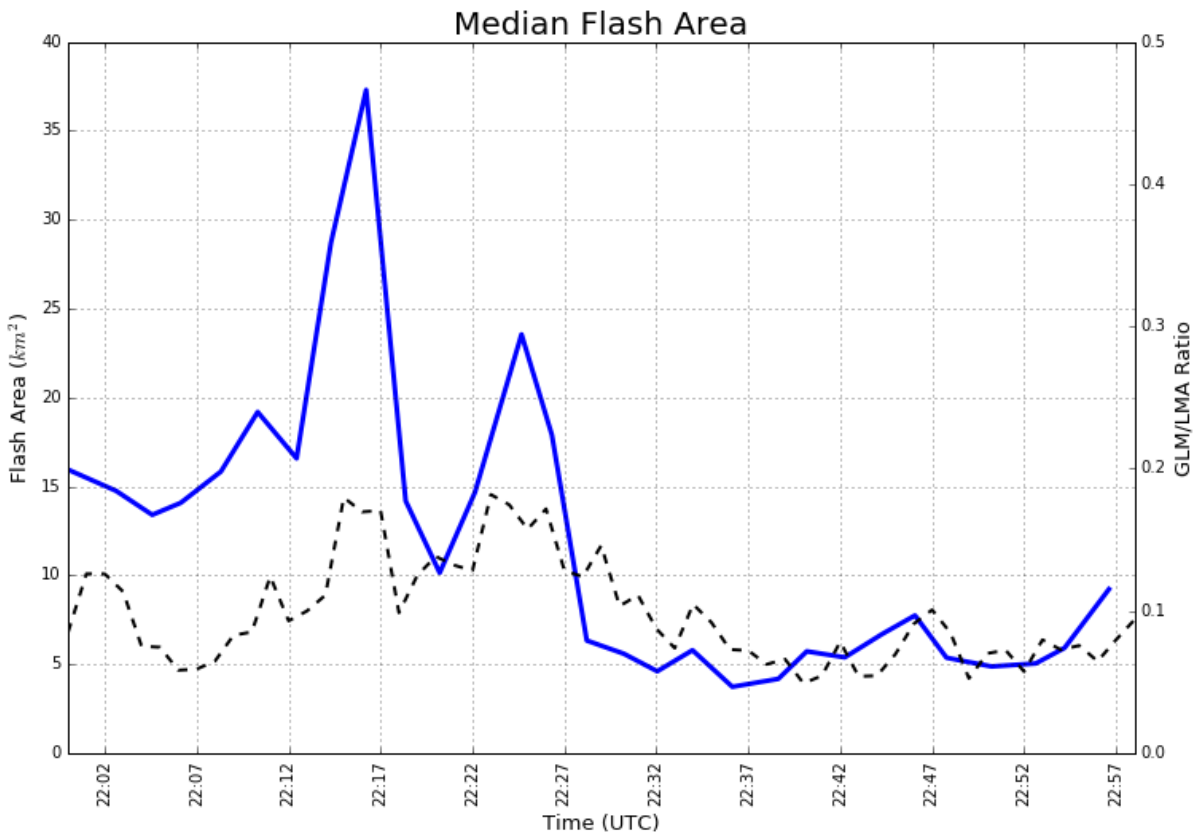


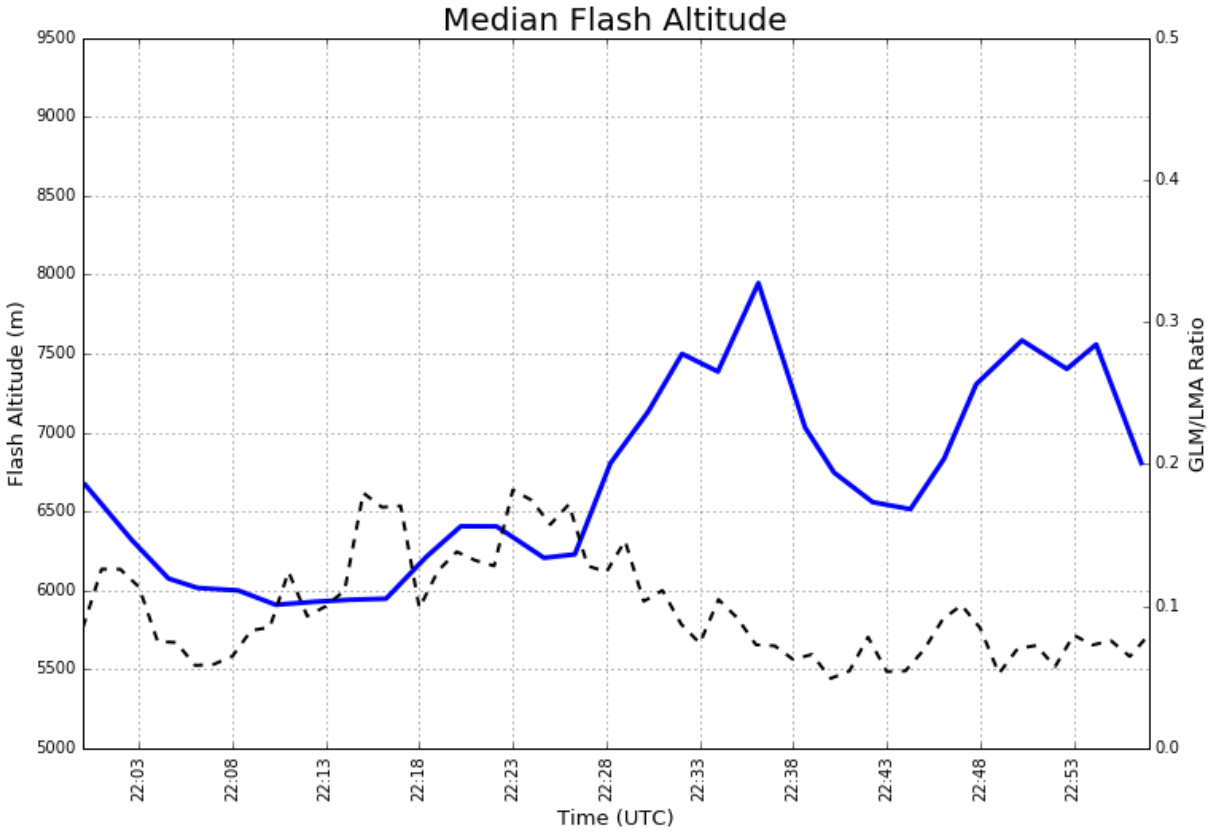


Vertical distribution of grid boxes for a particular flash

6 km

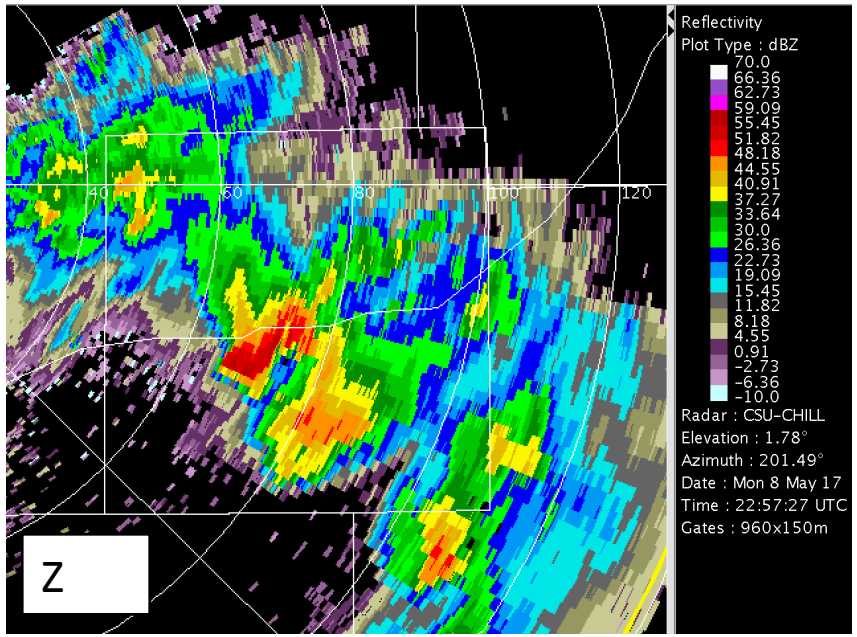
median flash area; median flash altitude

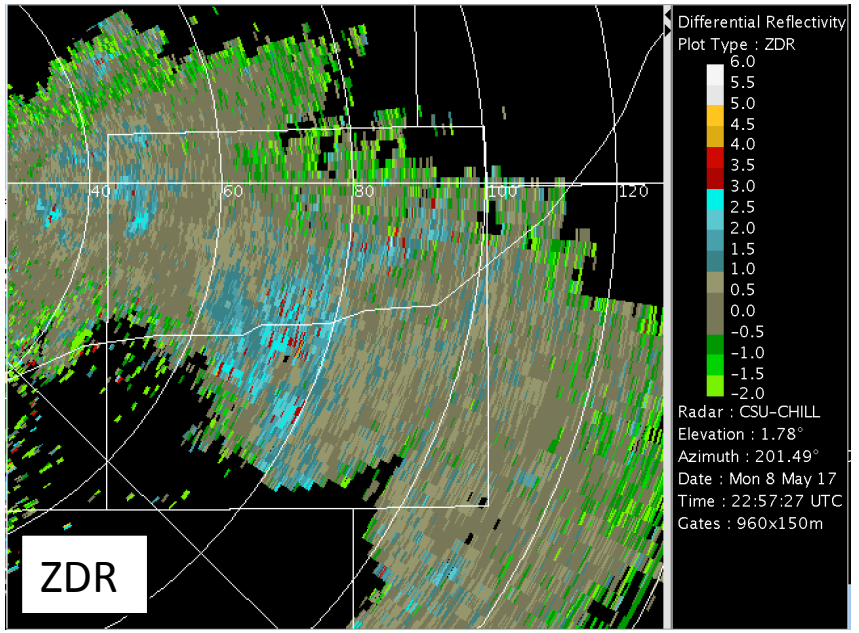


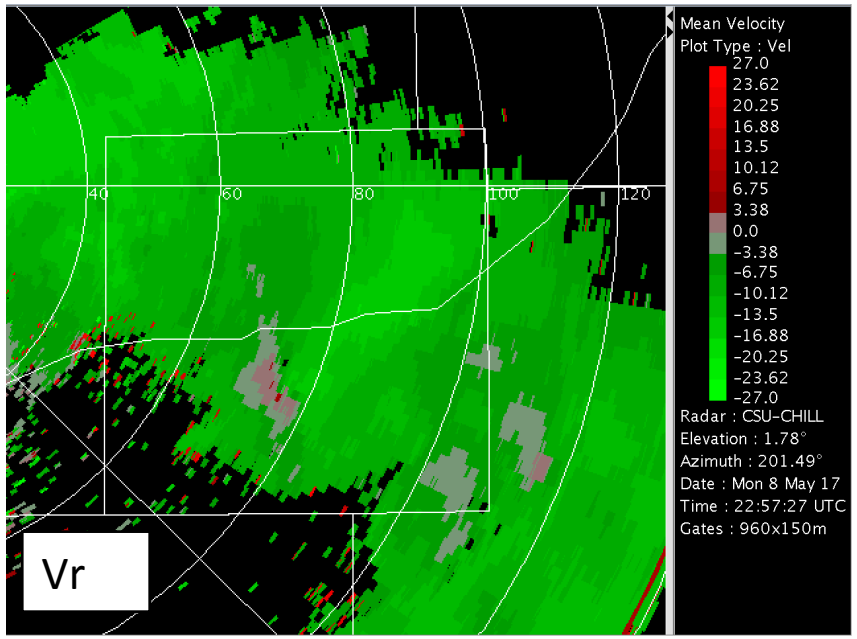


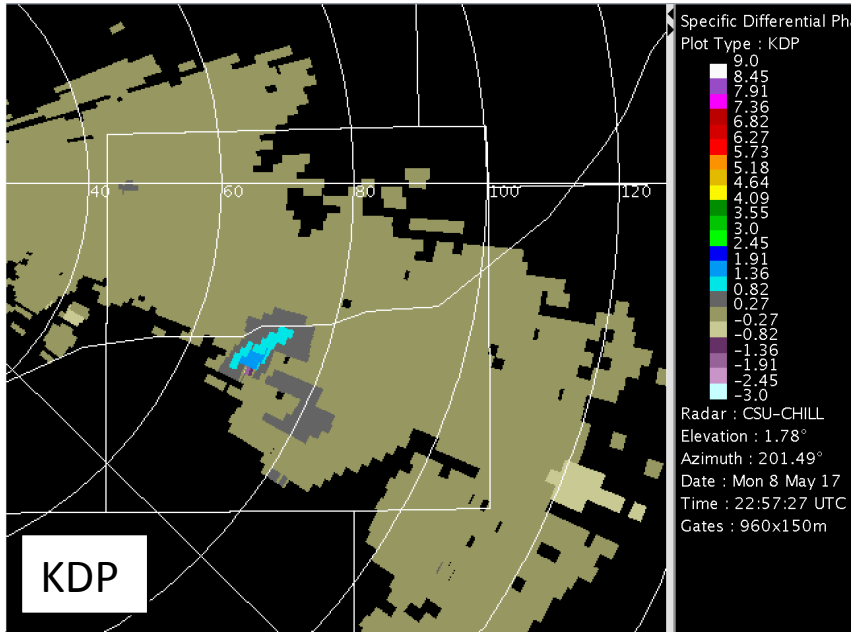
- Relative maxima in DE coincide with peaks in LMA-derived median flash size
- The DE "tracks" with flash area (flash size); DE decreases as median flash area decreases even though the median flash height increases; however these median flash heights are still fairly low, characteristic of anomalous storms (we will see later that flash heights are substantially greater in normal polarity storms which appears to impact DE)

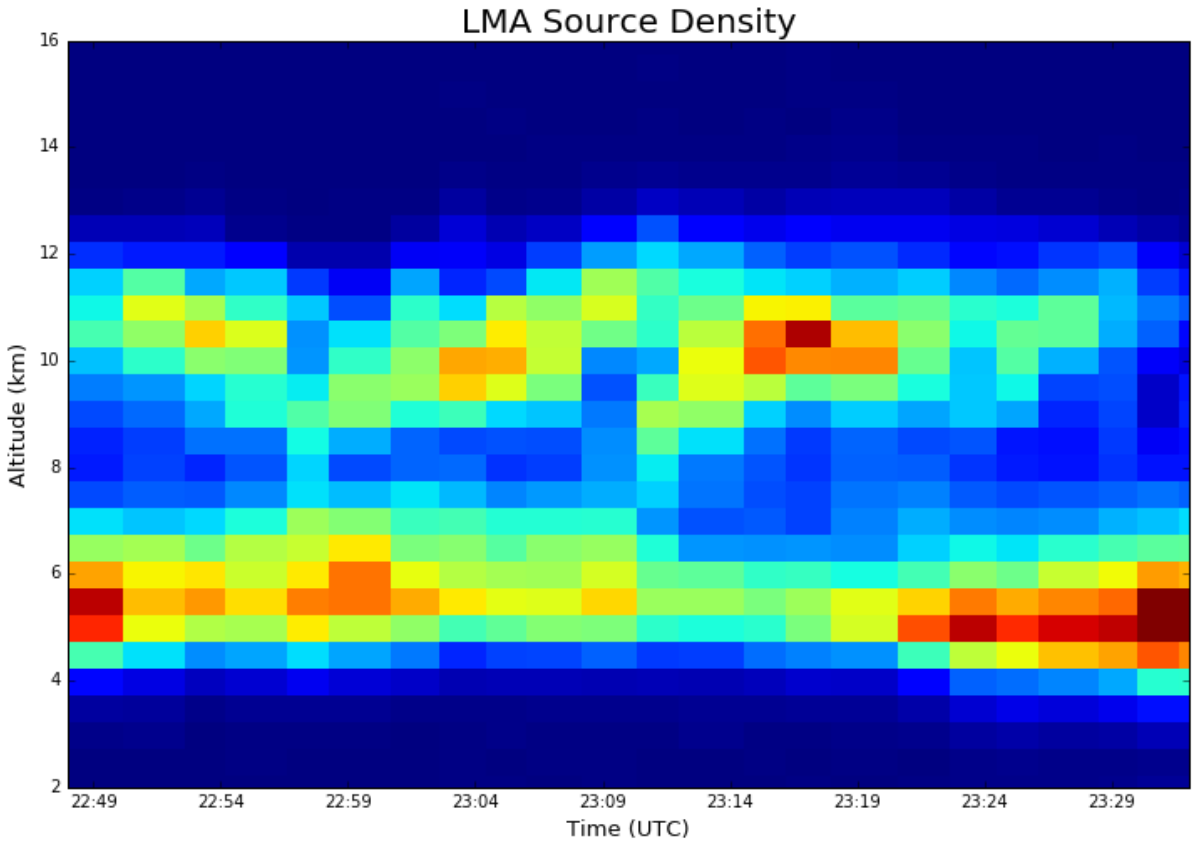
Fort Morgan Normal Polarity Storm



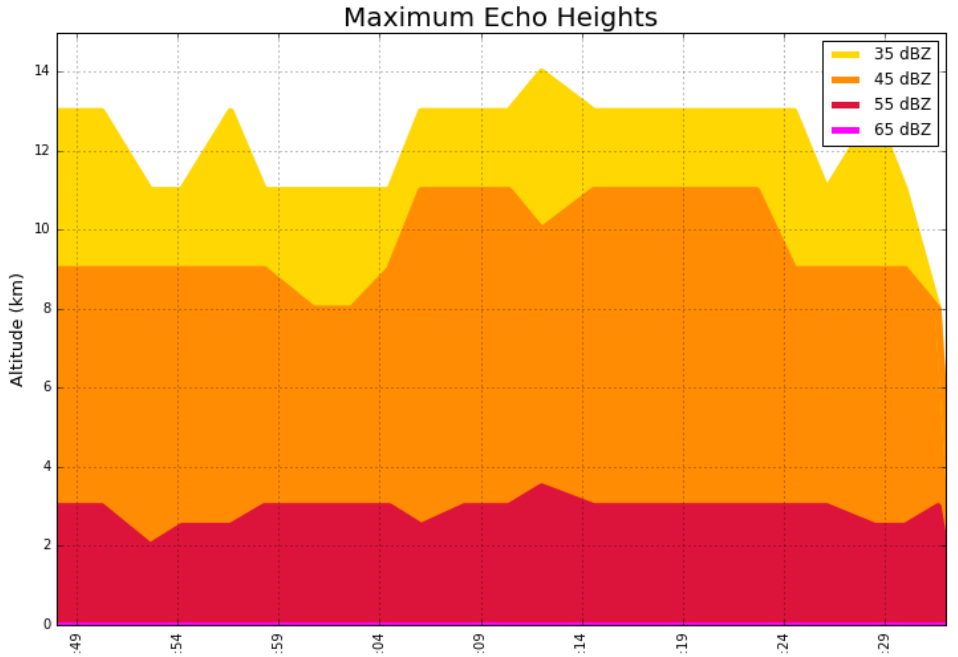




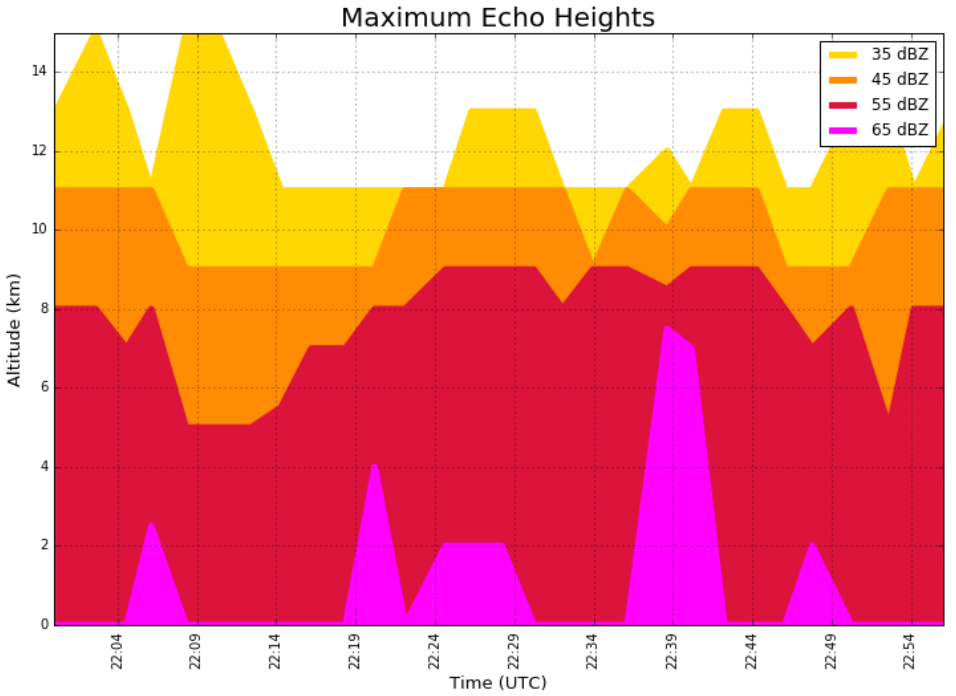




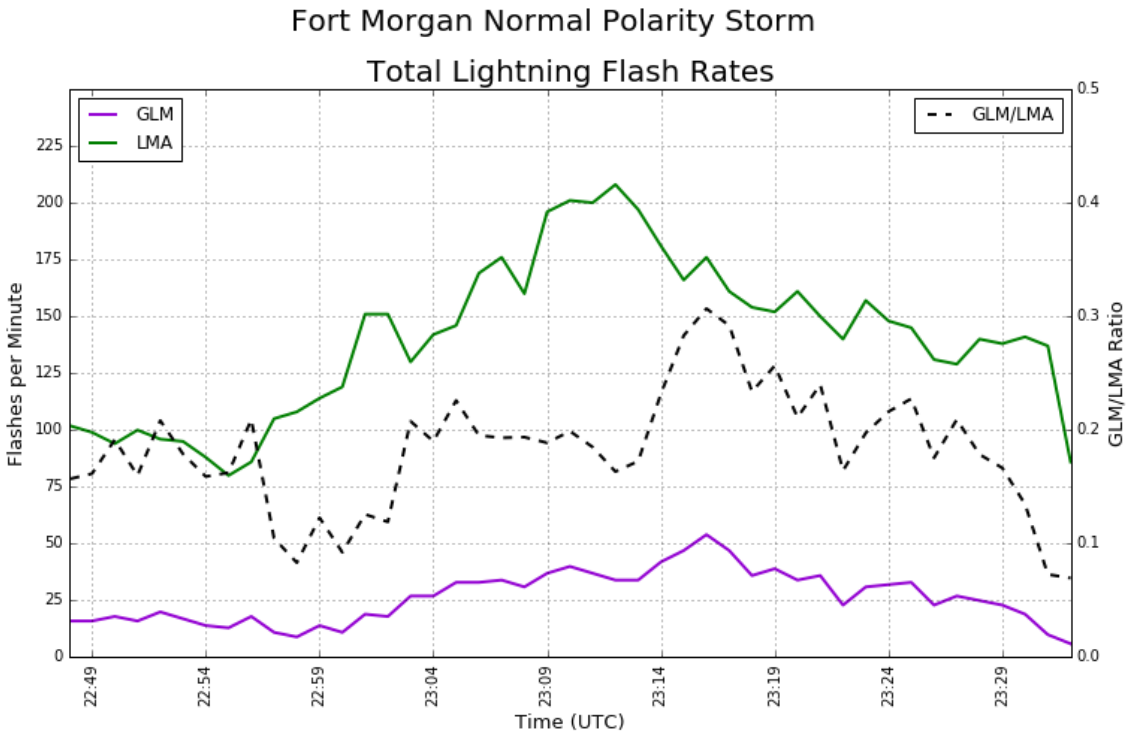
- LMA source density is bimodal in altitude, maximizing near 10 km and 6 km, suggesting a “normal” polarity storm
- Fort Morgan storm is weaker than the Greeley anomalous storm, evident in the vertical reflectivity structure

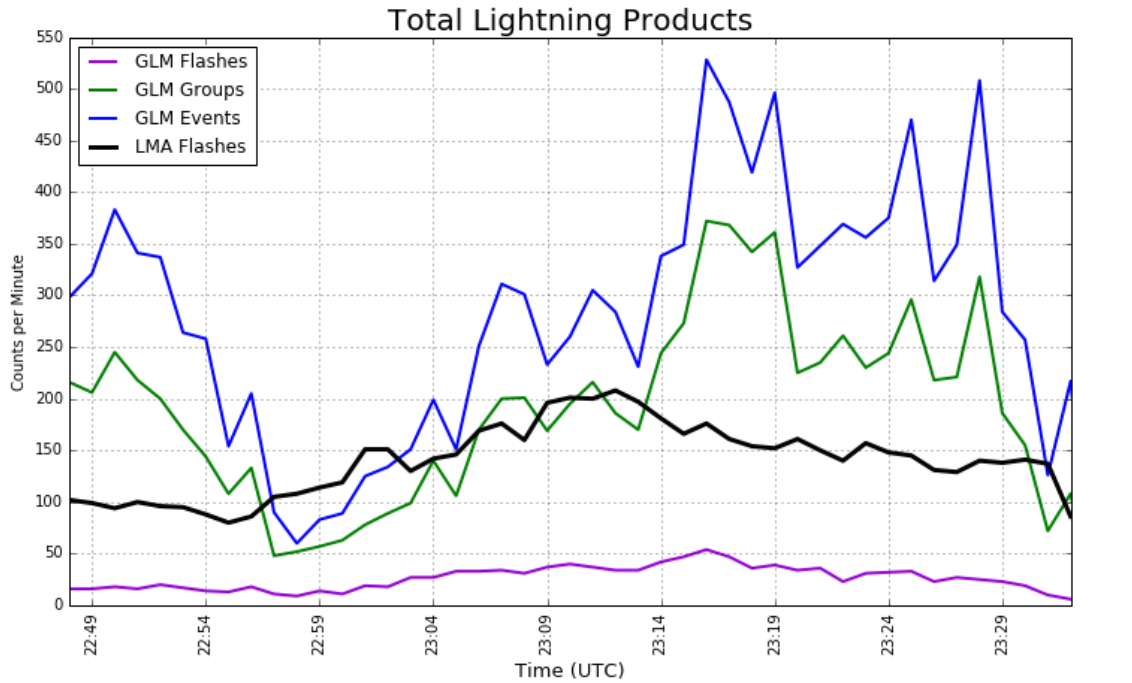


Ft. Morgan “normal” storm



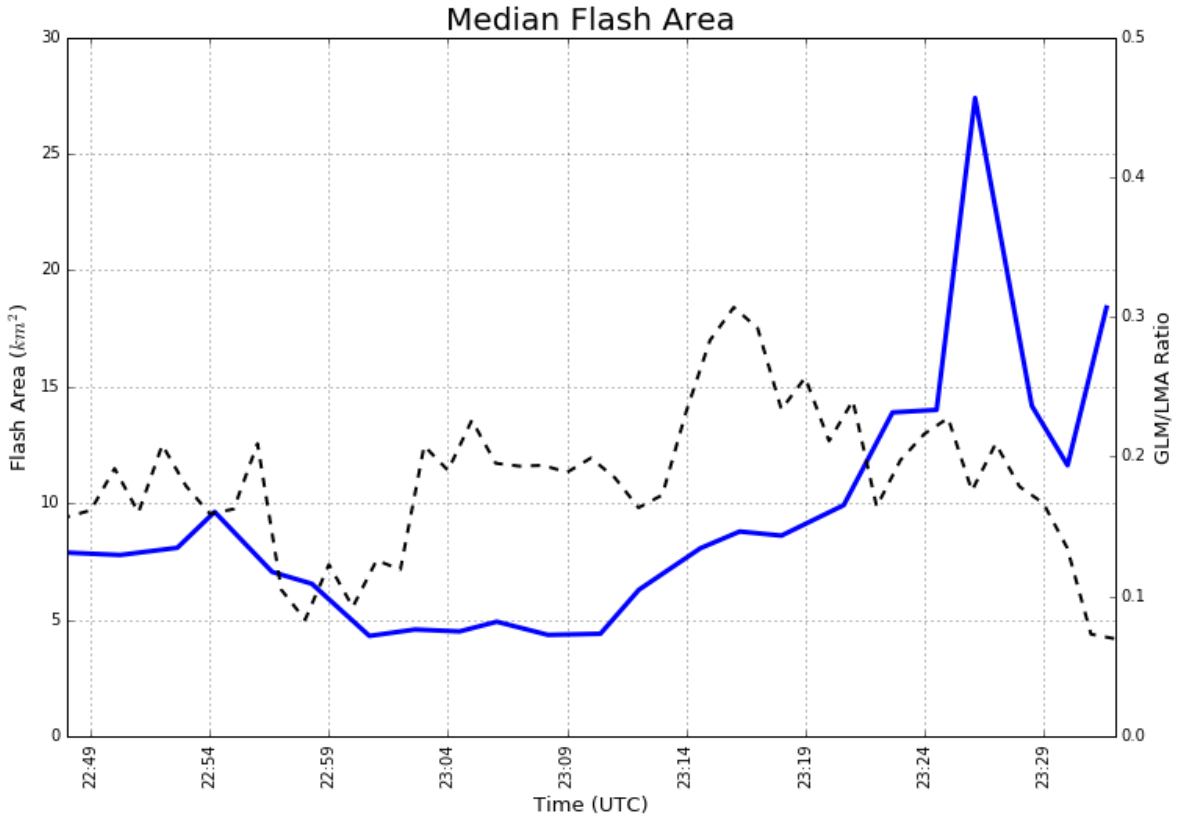
Greeley Anomalous storm for comparison

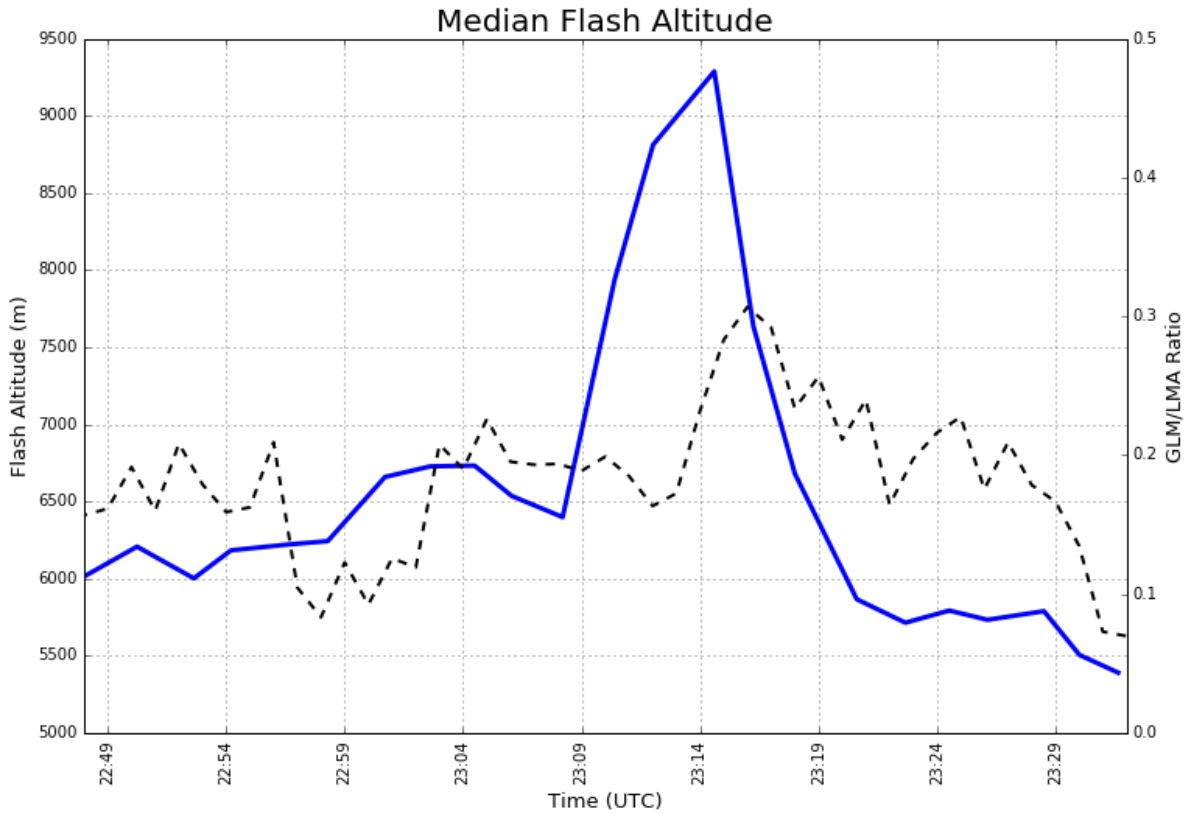




Fort Morgan Normal Polarity Storm

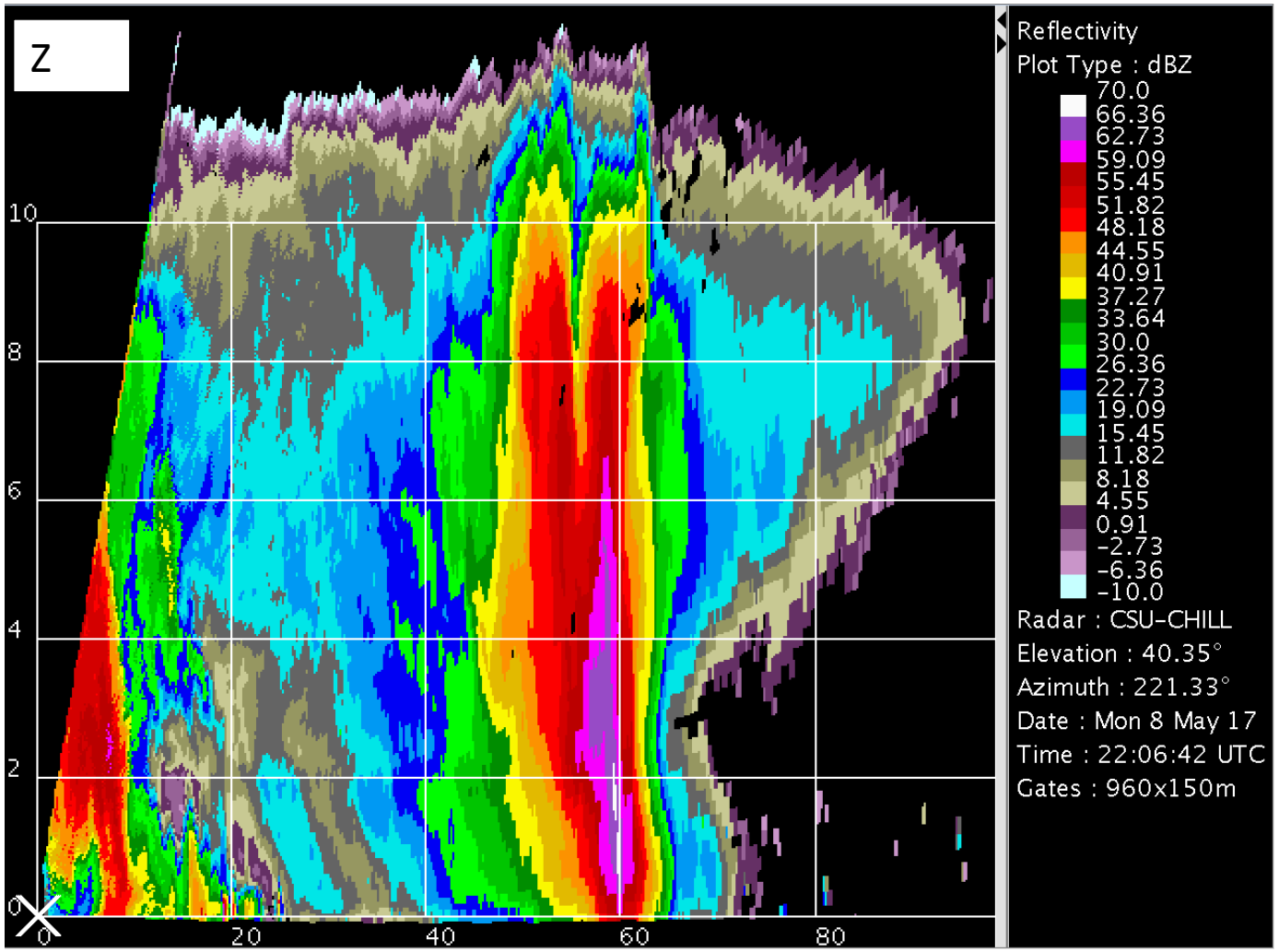
- GLM flash rate follows the LMA flash rate but LMA flash rates are significantly larger
- DE averages near 0.2 with peak values of 0.3; these DE's are somewhat higher compared to the previous case
- GLM events and groups are generally larger than LMA flash rates

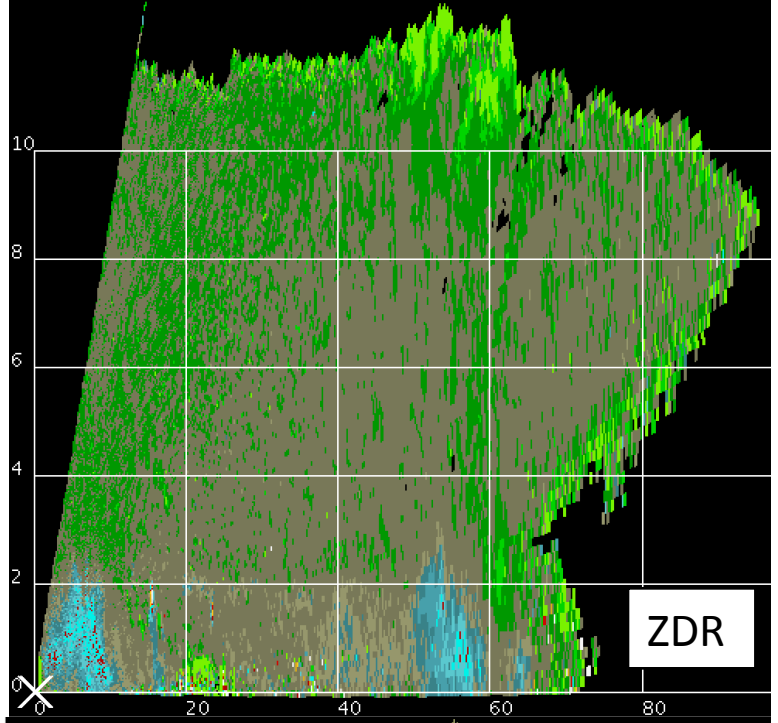


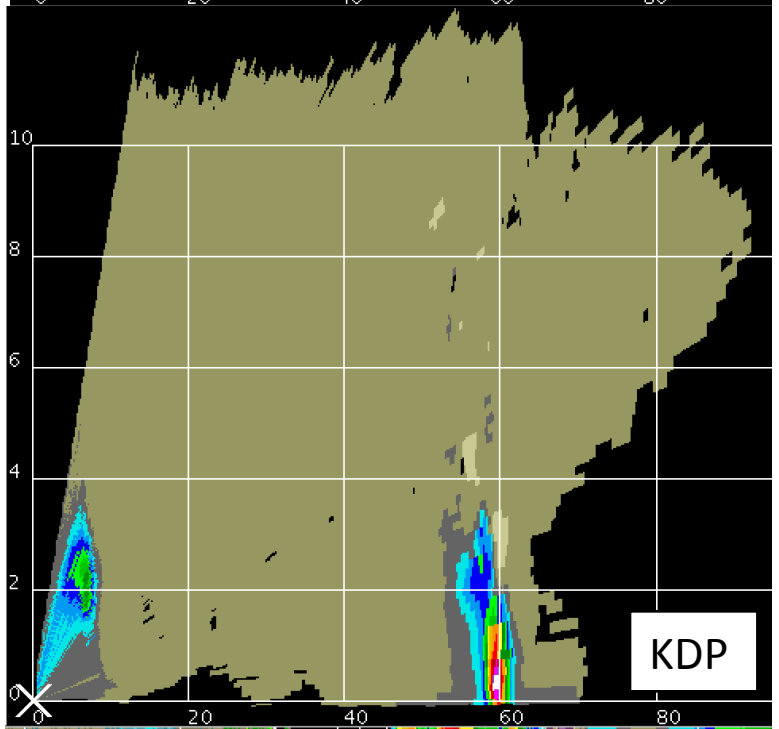


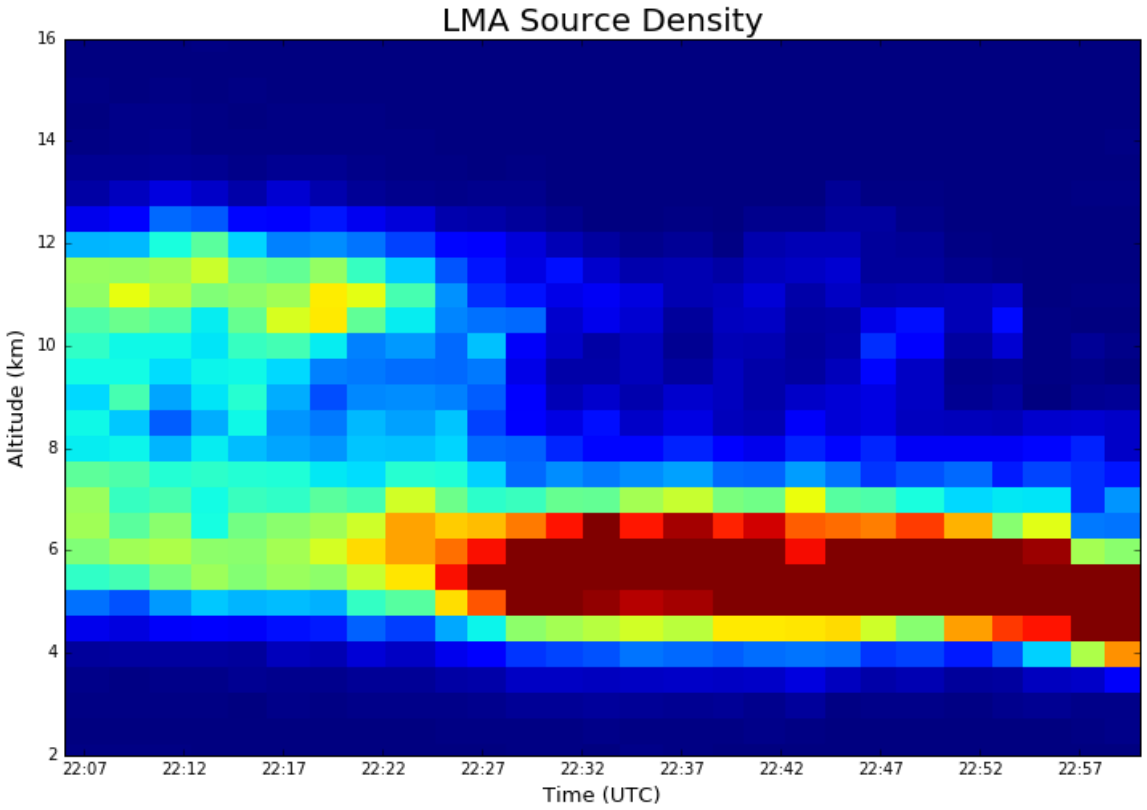
- Unlike the previous case, trend is unclear between DE and median flash area
- DE peaks when median flash altitudes are highest; note these peak flash heights are 2-3 km higher compared to the Greeley (anomalous) event

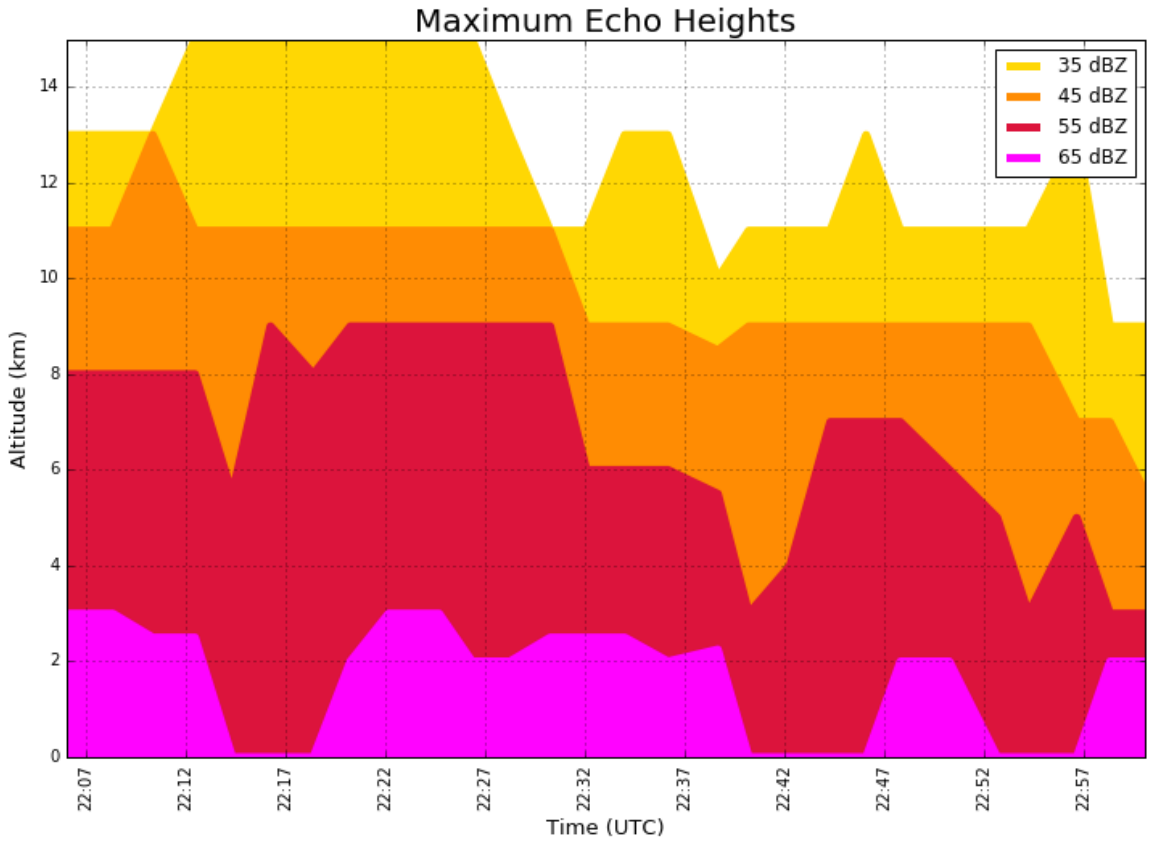
Denver Hail Storm



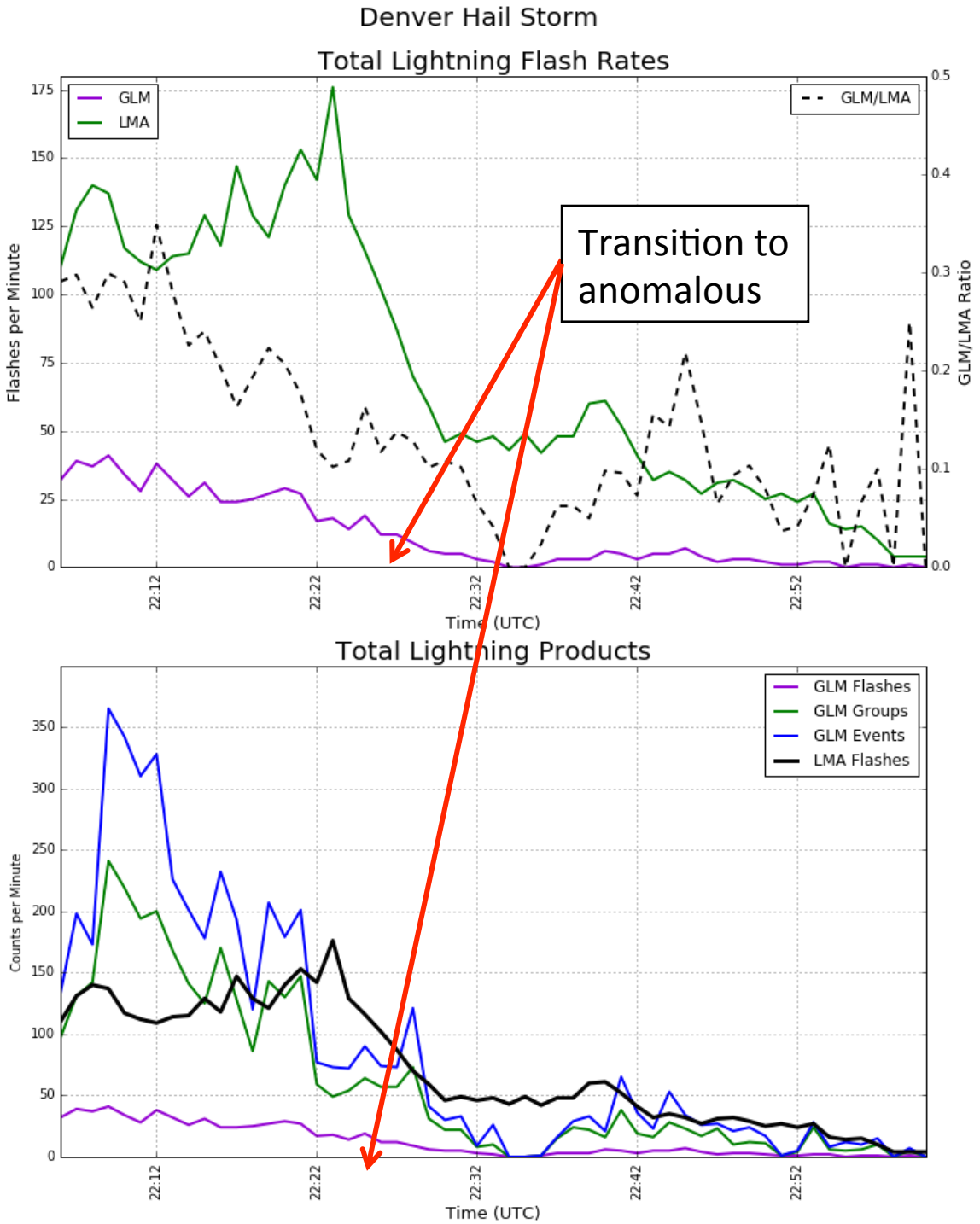






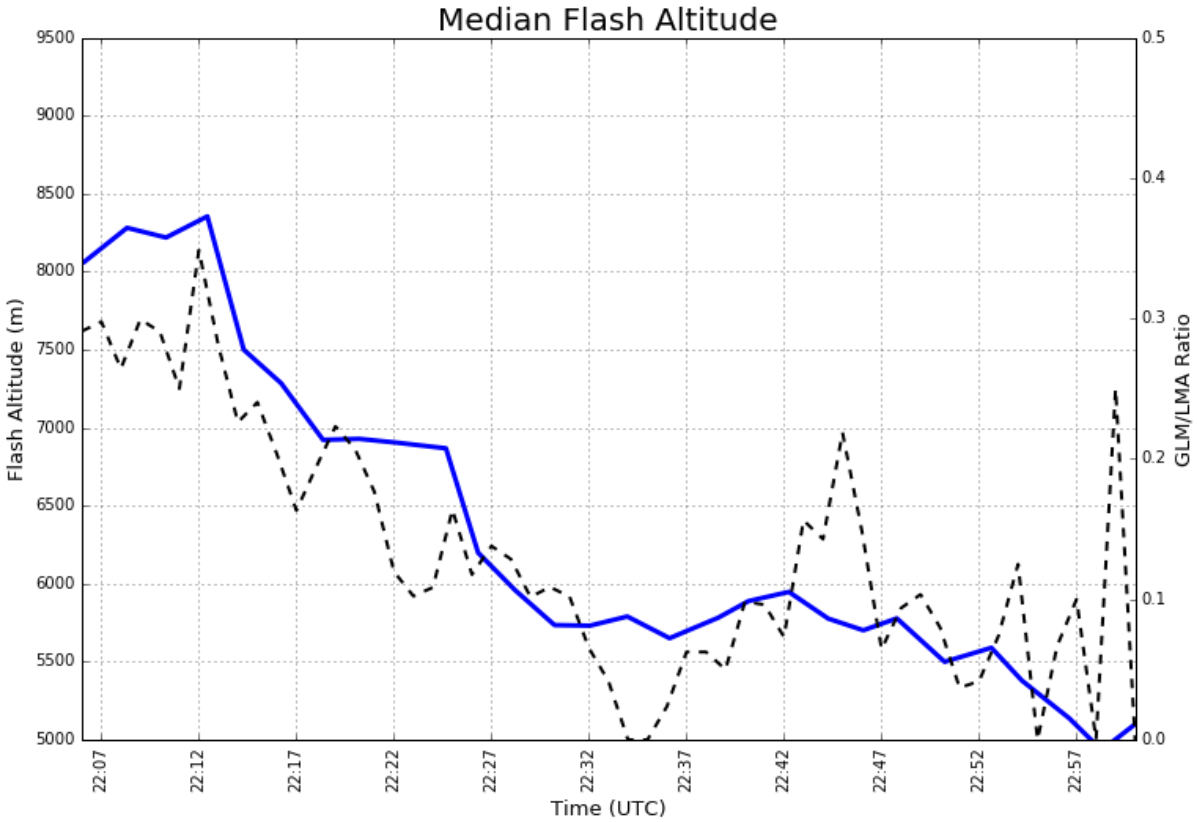


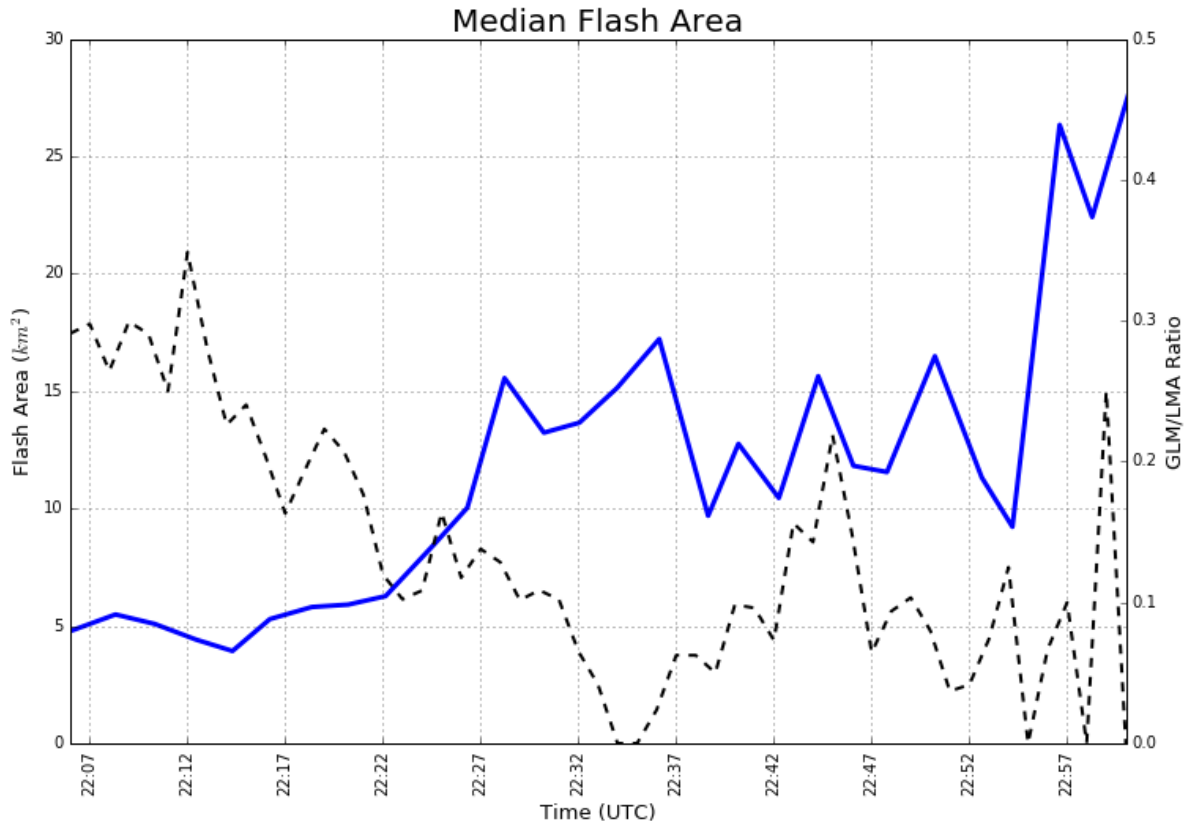
- LMA source density is bimodal initially, indicating a “normal” polarity structure
- LMA source density becomes concentrated near 6 km as the storm splits; suggesting a “anomalous” structure
- Maximum echo heights decrease during the later anomalous period consistent with reduced flash rates



Denver Hail Storm

- DE is highest early, then lower later in the time series (LMA flash rates are considerably lower in this later period compared to earlier)
- Transition from normal to anomalous polarity takes place around 2220 UTC
- GLM groups and events are larger than the LMA flash rate at first, but then transition to being similar to LMA flash rates in the later period





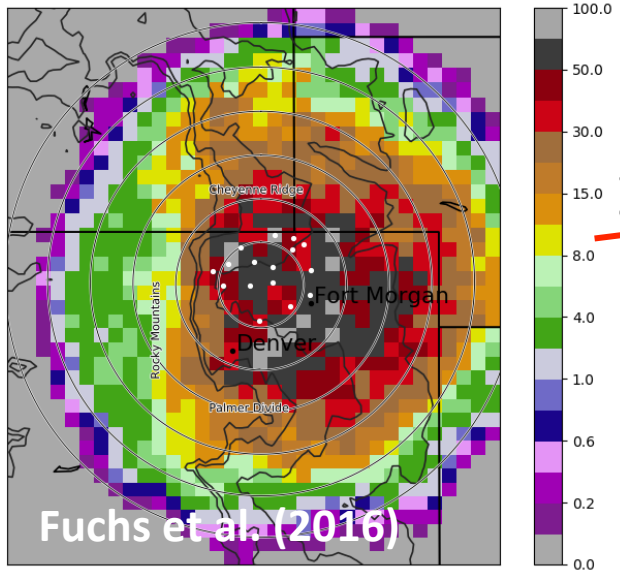
- DE is fairly high (~0.3) for the normal polarity phase, **when median flash altitudes are elevated** (even though the flash areas are small)
- Anomalous portion of the storm is characterized by low flash altitudes and reduced DE, even though flash areas are larger
- DE appears to follow median flash altitude perhaps more so than flash area---but its important to state here that we have only been able to examine a minute amount of data to date

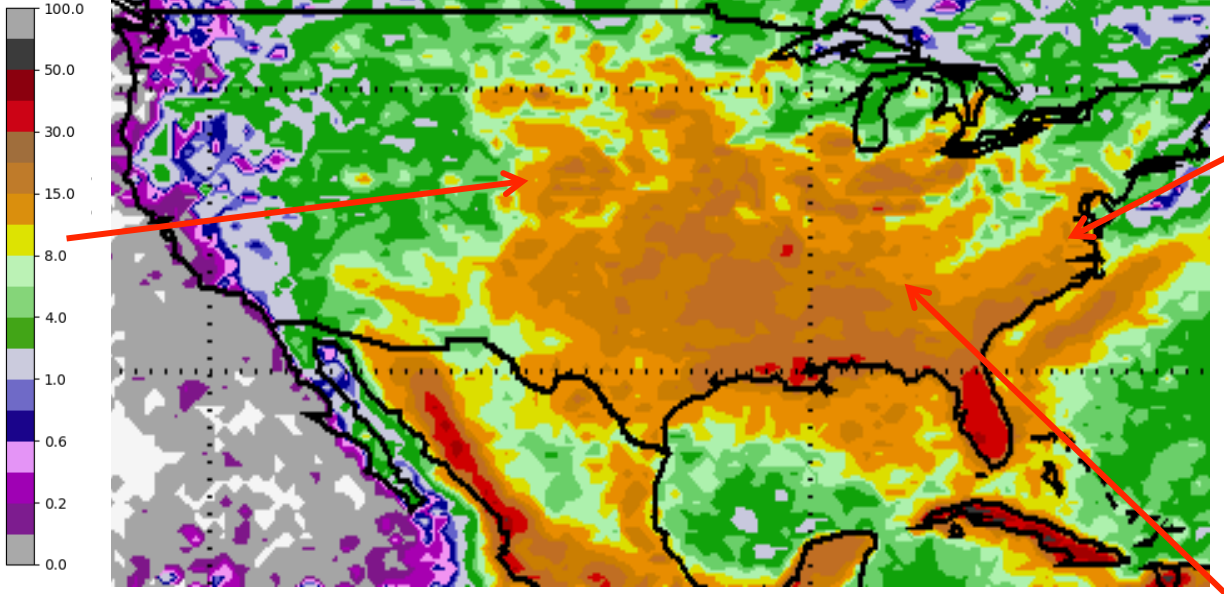
GLM/LMA Comparison Summary

- Normal polarity storms (Fort Morgan and beginning of Denver hail case)
  - Largest DE's
  - Enhanced GLM detection efficiency may be contributed by elevated flash channels
  - Flash altitude appears to play a larger role in flash detection than flash size, though both may impact DE's; need to analyze many more cases as more GLM is acquired over the available LMA networks
- Anomalous polarity storms (Greeley and end of Denver hail case)
  - Smallest DE's
  - Anomalous storms have low median flash heights and compact flashes. Also these storms are intense with large radar reflectivities extending to substantial heights so we need to see if significant ice water paths (IWP) may impact DE's in these cases

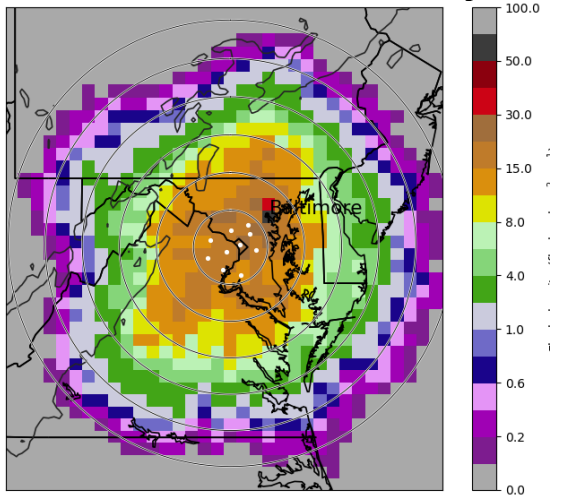
OTD/LIS FD vs. LMA FD

COLMA flash density

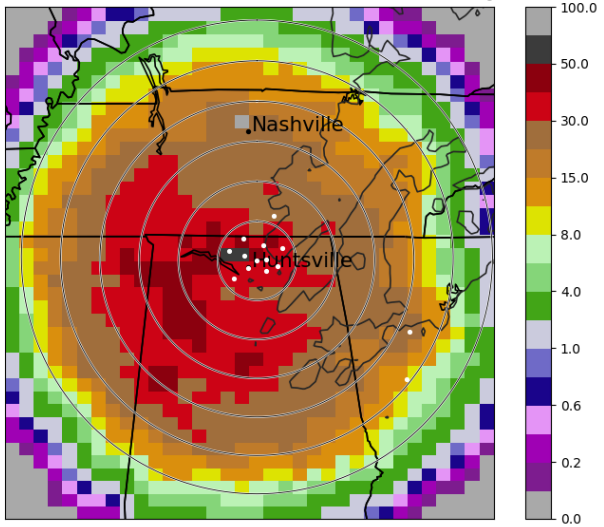




DCLMA flash density



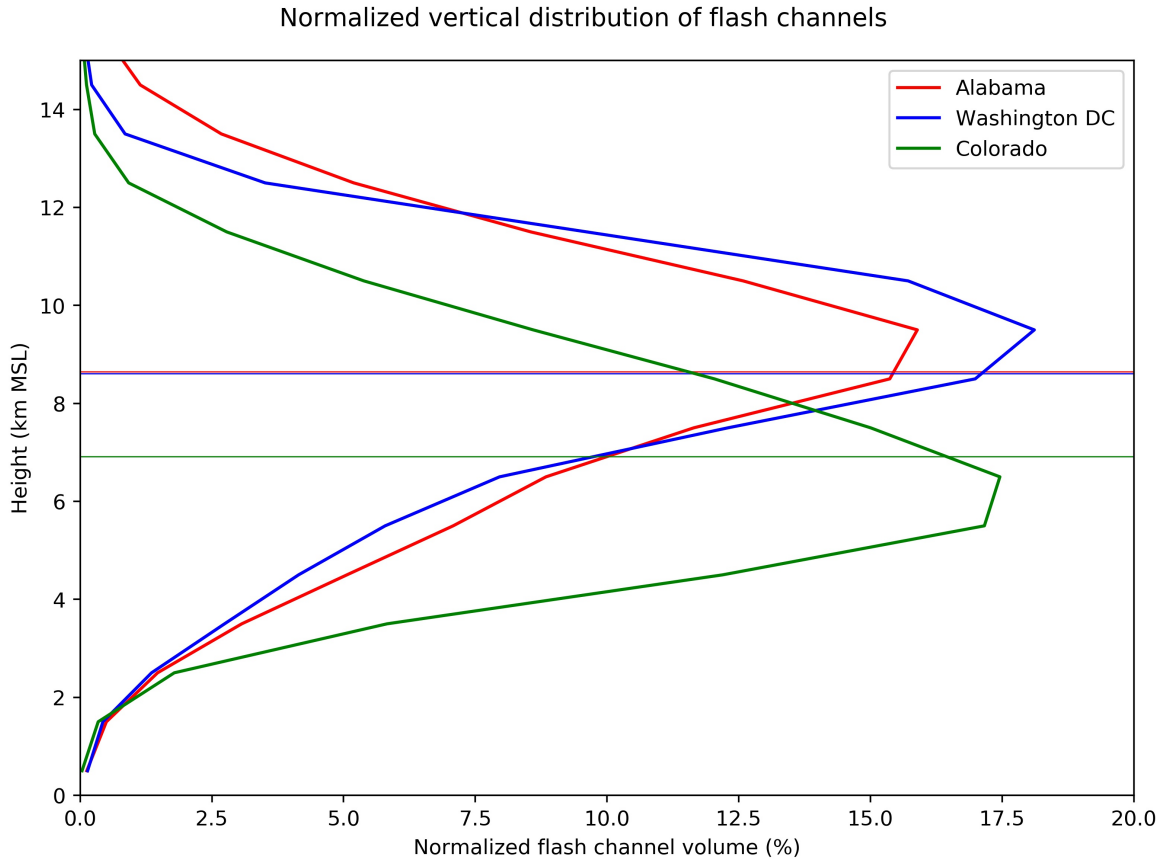
NALMA flash density



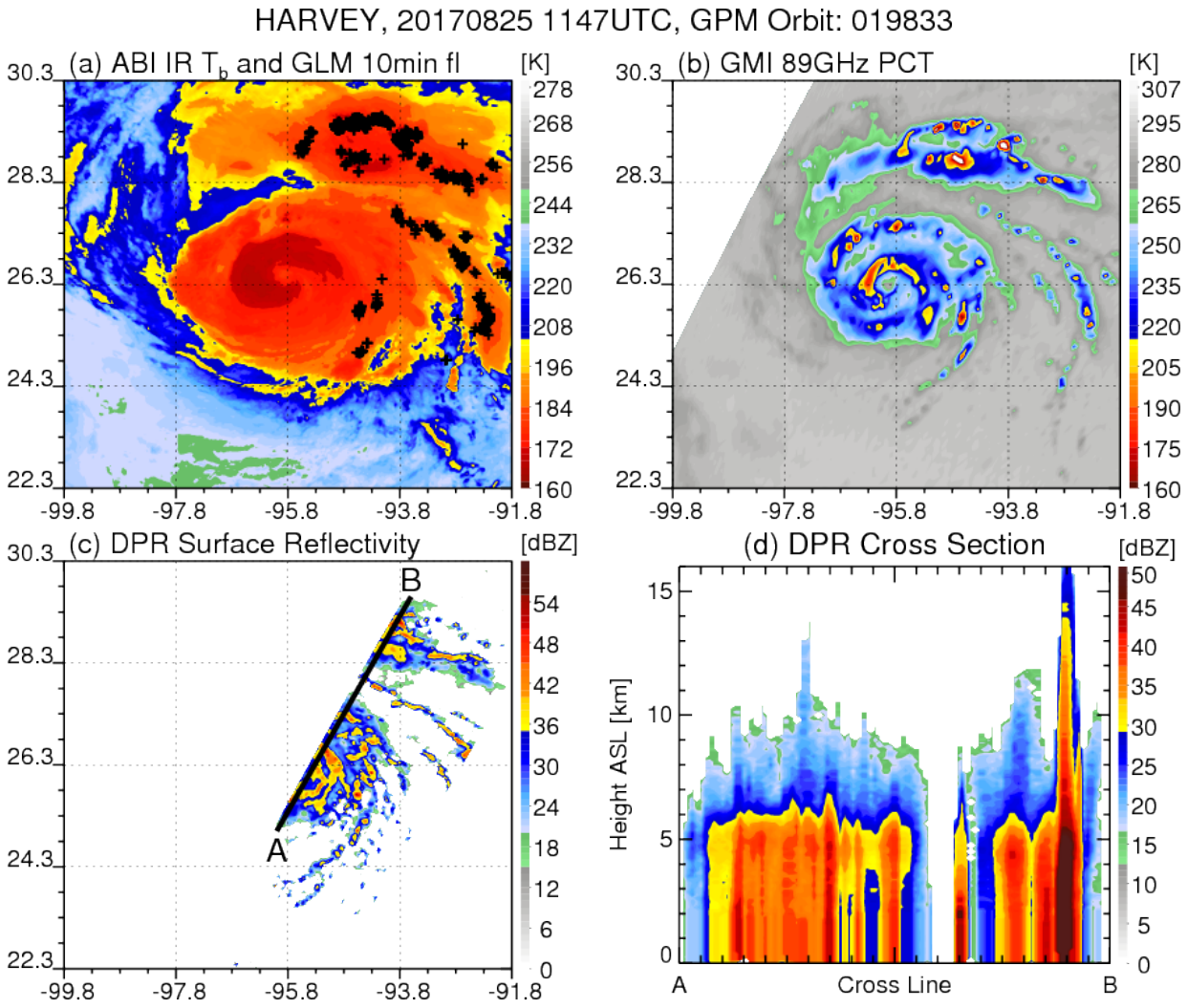
- Annual average flash density similar between LMA/satellite in AL and DC
- LMA about a factor of 3 higher in CO
- **Anomalous storms frequent CO; low flash altitudes, compact flashes and significant IWP. Do these factors lead to more undetected lightning events in anomalous storms?**

Regional flash channel distributions

- Average channel height in Alabama/DC ~8.5 km MSL
- Colorado much lower (<7 km MSL) associated with anomalous storms
- Approximately 100,000 flashes analyzed in each region



Hurricane Harvey



Xu, Rutledge and Zhang (2017)
JGR—In press.
Analyzed many TC overpasses by TRMM